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Wind power usage and prediction prospects in Lithuania

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Abstract

Wind power is not widely used in Lithuania yet. Currently only few small-scale wind turbines with total capacity of 0.995 MW are operating. However, Lithuania is planning to install wind power plants with total capacity of 200 MW by the year 2010. In this paper, wind energy resource assessment experience as well as current situation and future prospective of wind energy usage in Lithuania are reviewed. Main features of Lithuanian electrical system are presented and issues related to wind energy integration in electrical networks are discussed. The aim of this work is to point up the importance of wind power prediction in Lithuania. Thus a short review of wind power prediction methods is presented which has shown that selection of most suitable prediction models for Lithuanian conditions requires detailed research.

Keywords: Wind energy; Electricity; Wind power prediction; Numerical weather prediction

Contents

Abbreviations: a.g.l., above ground level; CFD, computational fluid dynamics; CHP, combined heat power; HPP, hydro power plant; HPSPP, hydro power storage power plant; MOS, model output statistics; NPP, nuclear power plant; NWP, numerical weather prediction

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1. Introduction

One of the largest problems of wind power, as compared to conventionally generated electricity, is its dependence on the volatility of the wind which is directly related to the meteorological conditions. Because of wind dependence on the weather, the wind power output cannot be guaranteed at any particular time. Thus integration of wind power into electrical grids can cause difficulties in the management in the power system. Knowledge of the expected wind power several days in advance would be a solution allowing to avoid problems of power system operation caused by fluctuating wind power. This is where wind power prediction comes in. Electrical utilities all over the world are beginning to realize the need for reliable wind power predictions, as the penetration of electricity generated by wind farms in the electrical grids is increasing.

Wind energy market in Lithuania is only at its early stage of development and current electricity market is almost completely occupied by conventional energy sources (Ignalina NPP and thermal CHP based on fossil fuels). As Lithuania has assumed the commitment to install additional 200 MW of wind energy plants till 2010, penetration of electricity generated by wind farms in the electrical grids will increase. This may cause difficulties in operating the power system because certain amount of spinning reserve will be needed to compensate wind power variations. However, these problems can be solved by means of wind power prediction, which also would promote the wind energy development in Lithuania.

2. Wind resource assessment in Lithuania

Investigations of wind energy resources in Lithuania began about 10 years ago. Our group has been studying technical and economical conditions of exploitation of wind power in Lithuania. Wind measurements were performed in coastal region for 10 years, the data of wind parameters from Lithuanian meteorological (met-office) stations were collected, the assessments of wind energy resources in various regions of the country were carried out. Also the experience of wind power usage in other countries was analyzed. According to those assessments areas for wind power plants were determined and methodologies for wind turbine selection and siting were created.

For performance of measurements German measurement equipment "WICOM-C" was installed in coastal region in Giruliai near Klaipeda. Wind speed was measured at 10, 30 and 50 m a.g.l. Results of measurements show (Fig. 1), that average annual wind speed in

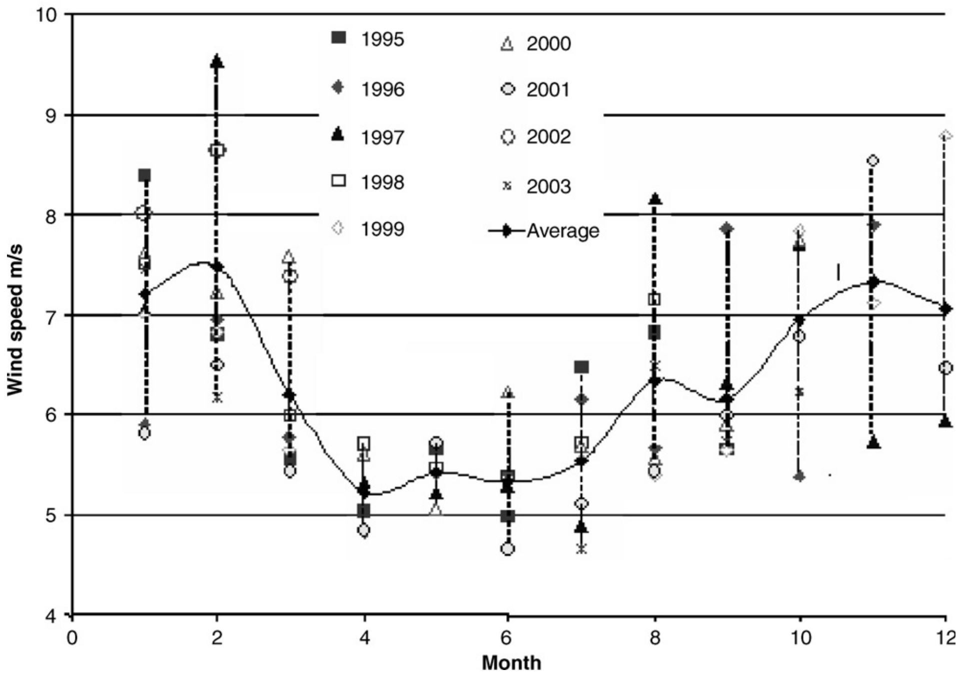

Fig. 1. Variation of average wind speed in Klaipėda region (Giruliai) 50 m a.g.l. in 1995–2003 [1].

the period 1995–2003 was 6.4 m/s [1] and wind speed here is sufficiently high for wind energy development.

The selection of the site for wind power plant construction is a very important task on which the efficiency of wind power plant depends. Therefore zones for wind power plants construction in Lithuania were selected by Lithuanian Energy Institute in regard to wind energy potential, possibilities of wind power plant connection to electricity distribution nets and environment protection requirements (Table 1). In these six zones the most suitable territories for wind energy development were distinguished. Available wind power capacity and produced energy was estimated, according to local meteorological, relief conditions and connection possibilities to the power grid.

Wind speed measurements in the territory of Lithuania were also carried out within the project "The Regional Baltic Wind Energy programme" sponsored by the Global Environmental Facility through UNDP. Measurements were performed in the western regions of Lithuania such as Kretinga, Vilkyciai and Taurage where the highest wind resources were expected.

Measurement equipment was mounted on existing antenna masts. Full 1-year data series for each site were obtained. The measured data have been analyzed according to the "Wind Atlas Method" [3]. Using the wind atlas method means that the measured wind data, by means of flow modeling, is transformed to a regional wind climate (wind atlas), where the local terrain effects have been cleansed away. The regional wind atlas thus contains wind statistics for a number of standard conditions: a number of standard surface roughnesses (Table 2) in combination with a number of heights above terrain.

Table 1
Selected zones for wind power development in Lithuania [2]

Zone	Maximum wind power capacity MW	Zone position
1	30	Distribution net
2	40	110 kV transmission net Klaipeda-Pagegiai
3	45	110 kV transmission net Klaipeda-Palanga-Sventoji
4	30	110 kV transmission net Sventoji-Zidikai
5	35	110 kV transmission net Klaipeda-Rietavas
6	20	Transmission net

Table 2
Roughness class explanations [4]

Roughness class	Roughness length, cm	Description
0	0	Water surfaces—sea or lakes
1	3	Very smooth grass land with few buildings and trees
2	10	Farm land with scattered houses and some higher vegetation (trees)
3	40	Closed landscape with vegetation; villages; woods

The wind resource program "WAsP" version 8 [5], developed by Risø National Laboratory, implements above mentioned methodology, and was consequently used for the analysis. The flow modeling includes the effect of surface elevation variations (orography), surface roughness changes and the near-field effects of wind obstacles (e.g. buildings, wind breaks). The terrain description used for the analysis of the measured wind data was obtained from available topographical maps, modern official map series and available Soviet-type maps.

In order to have some inland representation of the wind resources, the wind measurements from the present project were supplemented with data from the 16 national met-office stations for the period 1981–1990 + 1993–1998 provided by Lithuanian Hydrometeorological Service. Measurements at 10 m above terrain were converted to 50 m above terrain by assuming a flat surface with roughness class 2 (10 cm). After summarizing the results of all the investigations and the data from met-office stations the wind resource map was made (Fig. 2).

Wind atlas shows that the average annual wind speed in the coastal region of Lithuania reaches 6.4 m/s and more, which is similar to other countries of European Union. Therefore the coastal region is a suitable territory for wind energy development in Lithuania. These calculations are confirmed by Lithuanian Energy Institute measurements performed in Giruliai. However, average wind speed in most of continental area is only 3–5 m/s. Wind atlas represents statistical data and only the main features of wind climate. The precision of resource map is judged to be 5–10% as measurement equipment was mounted on antenna masts and measurement equipment used was not high precision [4]. Also additional wind speed data were taken from national met-office stations, which are situated in areas not best suitable for wind parameters measurement. The inland wind speed values in the resource map should be taken with precaution and only used to judge how fast the wind resource decreases with distance from the coast of the Baltic Sea.

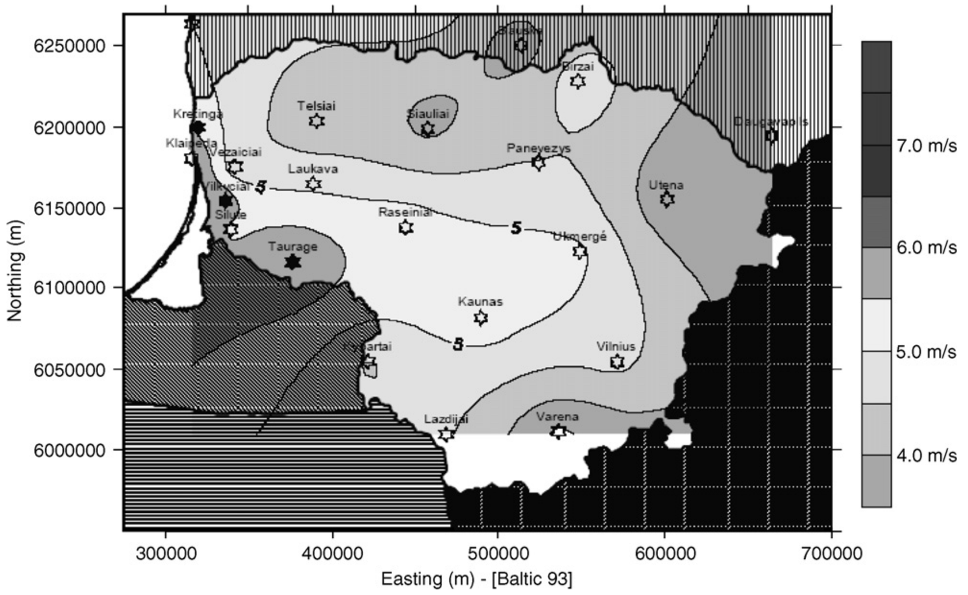

Fig. 2. Wind resource distribution in Lithuania: average wind speed at 50 m a.g.l. (roughness class 2) [4].

Although according to wind atlas in-land wind speed values are low, there can be sites in continental part of Lithuania with higher average wind speeds allowing the exploitation of lower capacity wind turbines. Also offshore wind energy development possibilities have not been investigated yet in Lithuania. In this field further detailed investigations are necessary.

3. Current situation and prospects of wind power development in Lithuania

3.1. Electricity generation in Lithuania

The main part of total electricity in Lithuania is produced by fossil fuel plants and Ignalina NPP. EU entry has forced the decommissioning of the first unit of Ignalina nuclear power plant in 2005. The second one should be decommissioned in 2009. Therefore a major issue concerning the future development of the Lithuanian electricity sector is the decommissioning of the second unit in Ignalina NPP. Such situation will present an opportunity for renewable energy use. Current and forecasted installed capacities for electricity production in Lithuania till 2010 is given in Table 3.

3.2. Wind power in Lithuania

Currently several small-scale (from 55 to 630 kW) wind turbines are producing electricity to the distribution grid. Their total installed capacity is 0.995 MW. The main reasons of low level of wind energy usage was the lack of promotion from the government. After the joining the EU Lithuania assumed a commitment to increase the usage of renewable energy sources. There are two main documents adopted in order to fulfil the obligation to

Table 3
Installed capacities of the power plants in Lithuania [2,6]

Power plants	Installed capacity, MW						
	2004	2005	2006	2007	2008	2009	2010
Ignalina NPP	2600	1300	1300	1300	1300	1300	0
CHP based on fossil fuels	2533	2533	2533	2558	n.d.	n.d.	n.d.
Kaunas HPP	101	101	101	101	101	101	101
Kruonis HPSPP	900	900	900	900	900	900	900
Small HPP	19.7	20	25	28	29	30	31
Industrial CHP	70.5	70.5	73.1	74.1	n.d.	n.d.	n.d.
Biomass	2.9	2.3	6.8	18.8	20.8	30.8	32.8
Wind	0.845	0.995	31	82	132	173	203
Biogas	1.2	1.95	n.d.	n.d.	n.d.	n.d.	n.d.
Total	6229,15	4929.7	4971.8[a]	5063.8[a]	5116.8[a]	5168.8[a]	3901.8[a]

n.d.–no data.
[a]Assumed without increasing of values with "n.d."

increase the share of electricity production from renewables [2,7]. In accordance with the EU Directive 2001/77/EC on electricity production from renewable energy sources, 7% of electricity is to be generated from renewable sources in Lithuania by 2010. However, in 2004 electricity generation from renewable energy sources including wind power comprised 3.7% of the total electricity balance in Lithuania [8]. Currently, the bulk of electricity produced by renewables (about 96%) is generated from hydro energy (Kruonis HPSPP not included).

It is estimated that Lithuania will produce a total amount of 13 TWh energy in 2010 and electricity generation from renewables will amount to about 0.995 TWh [2]. In order to ensure wind power generation share additional 200 MW of wind power plants must be built. The Government has set wind energy as a priority area and established the capacity requirement for wind power plants to be built yearly by 2010 (Fig. 3) [2]. It is predicted that around 320 GWh of electricity will be produced by wind farms in 2009 [2].

Furthermore promotion measures to make wind more attractive to investors were implemented by the National Control Commission for Prices and Energy. The comparison of purchase prices for electricity produced from renewable energy sources and other fuel-based power plants are given in Table 4. The price for wind power will be set at 6.4 eurocents per kWh and the price for all other renewables will be 5.8 eurocents per kWh.

These prices are valid until 2010 so wind energy is one of the main focus within the current renewable energy development in Lithuania. Tenders have been announced for wind power plant construction in the selected zones (see Table 1). It should be noted that electricity purchase prices for wind power plants are set for 200 MW.

4. Review of wind power prediction tools

Wind power forecasting is a multidisciplinary area requiring skills from meteorology, applied mathematics, energetics, software engineering, information technology and others. It appears as an emerging technology today, with leaders from the European Union

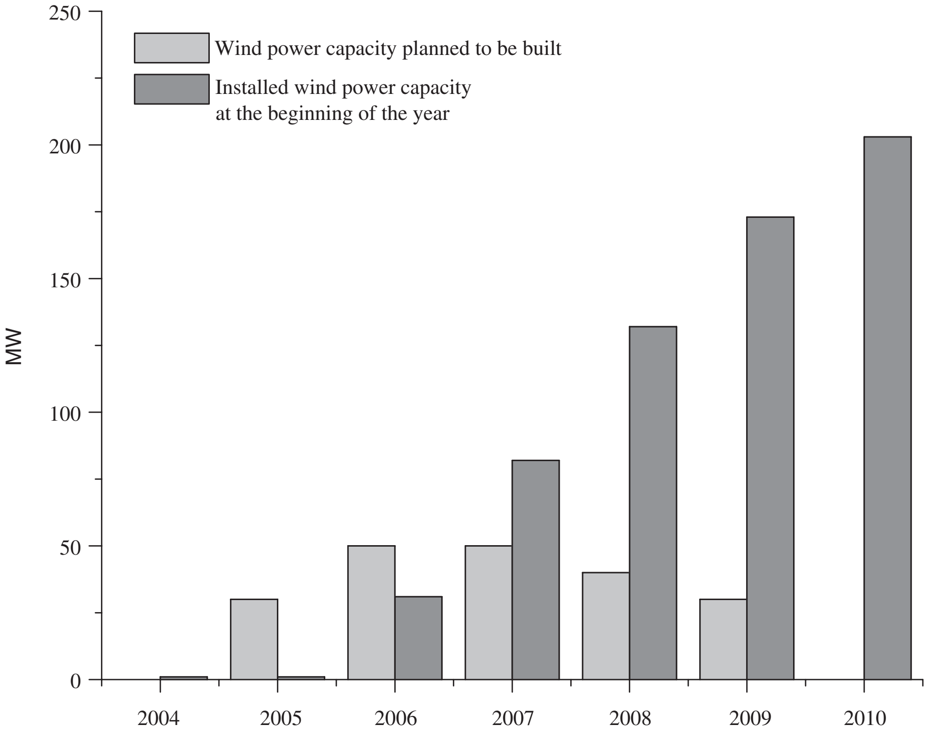

Fig. 3. Present and forecasted installed wind power capacity in Lithuania till 2010.

Table 4
The cap of electricity purchase prices [9–11]

Power plant according to fuel source		Price, ct.LTL/kWh[a]
1	Hydro power plants	20 (~5.8 €cents)
2	Wind power plants	22 (~6.4 €cents)
3	Power plants, using biofuel	20 (~5.8 €cents)
4	Fossil fuel power plants	
	Industrial CHP	7.8 (~2.26 €cents)
	Thermal CHP	10.88–12.9 (~3.15–3.74 €cents)
5	Ignalina NPP	6.58 (~1.91 €cents)

[a]Without VAT.

Institutes. The expectations from short-term wind power forecasting today are high since it is recognized as the means to allow wind power to compete with traditional energy sources in a competitive electricity marketplace.

Wind power forecasting is currently recognized as a cost efficient solution able to provide adequate information on the production of wind parks in the next hours up to next days. Predictions of wind power production up to 48 h ahead contribute to a secure and economic power system operation [12].

Three wind power prediction horizons are interesting for utilities:

- a *short horizon* for the scheduling of conventional power plants (4–8 h ahead);
- a *longer horizon* for an optimal trading of wind production in an electricity market (up to 48 h ahead);
- a *long horizon* for maintenance planning (all the way to weeks ahead) [13].

The main requirements for wind prediction are as follows:

- Forecasts of wind power output in MW rather than wind speed and with error bars;
- Forecasts should be available for individual wind farms and groups of wind farms;
- Hourly forecasts with prediction horizons of at least 48 h [14].

For prediction horizons of few hours, one can use a time-series analysis model coupled to climatology, but for even medium horizons, the accuracy of the model is getting much better by using numerical weather prediction (NWP), typically from the local meteorological institution [15]. Therefore, all models employed by utilities use the NWP approach. Selection of the model for wind power prediction depends on the horizon one wants to predict.

Developing models for wind power prediction is by no means a trivial task, as the underlying system covers everything from the large-scale atmospheric flow, influence by local topography, vegetation and atmospheric conditions to the wind farm layout and the single turbine. This system, including each single component, is by nature non-linear and non-stationary.

4.1. Classification of wind power prediction models

Short-term prediction of wind farm power production has already been the subject of extensive research. In principle there are three categories:

- models based on local measurements (uses time series analysis techniques with statistical models or neural networks);
- models based on NWPs;
- models based on a combination of both local measurements and NWPs [16].

Whether the inclusion of NWPs is worth the effort and expense, depends on the desirable prediction horizon.

Basically short-term prediction can be performed in two ways: by *the physical* and *the statistical* approach. In some models a combination of both is used, as indeed both approaches can be needed for successful forecasts. In short, the physical models try to use physical considerations as long as possible to reach to the best possible estimate of the local wind speed before using Model Output Statistics (MOS) to reduce the remaining error. Statistical models try to find the relationships between many explanatory variables including NWP results and online measured power data. This is usually done by recursive techniques.

There are different classifications of models. In the following list for most of the criteria, complexity increases from left to right [17]:

- Dynamics—kinematic (mass-consistent), hydrostatic, non-hydrostatic;
- Advection—linear, non-linear;

- Time domain—diagnostic, prognostic;
- Spatial scale—microscale, mesoscale, synoptic;
- Stratification—neutral, non-neutral;
- Friction–frictionless, turbulent closure;
- Formulation—analytical, spectral, grid point;
- Type—flow model, wind climate model.

In reality the classification is more complex. For example, WAsP is a linear model; however, the interaction of its stability model and the roughness change model is non-linear. Also, its hill flow model assumes neutral stratification, but the mean wind field is for non-neutral stratification. WAsP employs polar coordinates. Consequently, it is not periodic, though it is a spectral model [17].

Mass-consistent models contain no dynamic equations, they only require the flow field to be divergence-free. Therefore they require many observations in order to model the flow field correctly [18,19].

In models with a horizontal resolution coarser than 5–10 km the hydrostatic approximation is normally used, so hydrostatic models should only be used to model the regional wind climate. Consequently in models with higher resolution the hydrostatic assumption will lead to wrong phases of the speed-up above hills and mountains, so for complex terrain non-hydrostatic models should be used.

Most linear, spectral models solve variations in the horizontal directions, assuming periodic domains. Most linear models are diagnostic models. They are very fast and easy to use and this makes them very attractive. Linear models cannot calculate detached flow, which occurs in steep terrain. They are used to model wind flow over flat and hilly terrain which is sufficiently gentle to ensure mostly attached flow, corresponding to landscapes where the slopes are less steep than about 0.3. Typical horizontal dimensions of the hills are a few kilometers or less [17].

Non-linear models require more computing resources. The scale of the model influences which forces must be included in the model, e.g. in a terrain where the length scale of the variations is less than approximately 10 km, Coriolis forces are not important for calculating the perturbations from the mean flow.

Atmospheric mesoscale models are grid point models and they should have open boundaries [17]. They have higher resolution and usually are used in cases when smaller scale wind flow must be modeled.

Due to the differences in the existing applications (flat, complex terrain, offshore) it is difficult to compare prediction systems and decide which is better. Wind power prediction software is not "plug-and-play" because it is always site-dependent. After installation to a new site, in order to run model with acceptable accuracy, considerable effort must be devoted for tuning the models (in an off-line mode) on the characteristics of the local wind profile or on describing the surrounding environment of the wind farms. In this field the experience of the installing institution is most important [20].

4.2. Typical model chain

If the model is formulated rather explicitly, as is typical for the physical approach, then the stages are *downscaling*, *conversion to power*, and *upscaling* (Fig. 4).

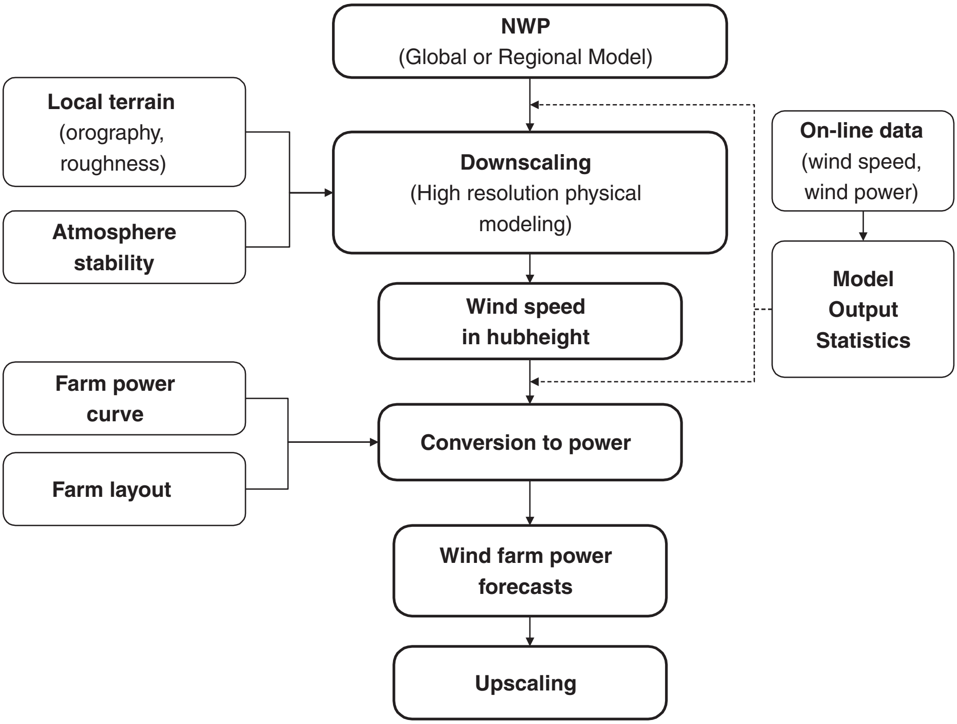

Fig. 4. Typical wind power prediction model structure scheme.

The input wind is taken from a NWP model. As the NWP model consists of several levels, the best-performing NWP level must be selected and the wind speed and direction from this level must be scaled to the hub height of the turbine. This can be done in two general ways: if the NWP wind is taken from one of the higher levels in the atmosphere (geostrophic wind), then geostrophic drag law and logarithmic profile is used, and if the wind is NWP offering for the wind at 10 m a.g.l., logarithmic profile is used directly [15].

The resolution of NWP models is usually too coarse (7–25 km) to resolve local flow patterns, therefore additional physical considerations of the wind flow are needed to transform NWP wind to local conditions of the wind farm site. This step is called *downscaling procedure*. Local effects are typically associated with orography, roughness, near-by obstacles and the presence of other wind turbines. Also the influence of atmosphere stability must be included. The roughness length can be derived from a specification of the land-use and vegetation coverage.

The physical approach uses a mesoscale or microscale model for the downscaling. The difference between these models is mainly the maximum and minimum domain size and resolution attainable. In some models a CFD module is used which performs a very high-resolution simulation of the wind flow over the wind farm, reaching a spatial resolution of meters. In some cases, when the NWP prediction is already good enough, the use of a mesoscale model is not necessary.

The downscaling yields a wind speed and direction for the turbine hub height. This wind is then *converted to power* with a power curve. The power curve is usually the one delivered

by the manufacturer, but it can also be estimated from forecasted wind speed and direction and measured power.

Depending on forecast horizon and availability, measured power data (on-line) can be used as additional input. If on-line data is available, statistical model (MOS) is used for improving the residual errors and overall prediction quality. The statistical models can be used at any stage of the modeling. However, often only off-line data is available, with which the model can be calibrated in hindsight.

If only one wind farm is to be predicted, then the model chain stops (maybe adding calculations of wind turbine wake losses). If all wind farms in an area must be predicted, the *upscaling* from the single results to the area total is the last step. In some cases this would involve a simple summation, in other cases some farms are chosen to serve as input data for an upscaling algorithm. It should be noted that the error of distributed farms is reduced compared to the error of a single farm [15].

Not all short-term prediction models involve all steps. In some cases leaving out few steps can be an advantage. That depends on the requirements to wind power prediction.

There is a wealth of wind power prediction models currently available, either commercial or research models. More advanced wind flow models are coming into play, like mesoscale models and CFD. Forecast tools for wind power production are under continuous development and they will be improving.

5. Prospects of wind power prediction in Lithuania

Wind power prediction tools have not been in use in Lithuania yet because wind energy is not widely used and wind flow modeling is at early stage. However with the increase of wind power penetration in the nearest future wind power prediction will become necessary. Wind power forecasts would allow wind power to compete with traditional energy sources in Lithuanian liberalized electricity market. Accurate forecasting of power inputs from wind farms into the grid could improve the image of wind power in Lithuania by reducing the oncoming network operation problems caused by wind power fluctuations. Also wind power forecasts will be necessary for electricity producers and transmission system operators to optimize the scheduling of wind power plants.

As predictions of wind power production rely almost entirely on meteorological forecasts, NWP models are needed. Weather forecasts are made in Lithuanian Hydrometeorological Service, but still there are no numerical weather forecast tools implemented. Currently works of HIRLAM model adjustment to Lithuanian territory are being performed by Lithuanian Hydrometeorological Service's Climatology Section. Neither wind flow modeling over Lithuanian territory nor statistical wind data investigation for wind power prediction have been performed yet, therefore extensive research in this field is necessary.

Lithuanian terrain should be prescribed to flat and hilly terrain which is generally within the performance limits of linearized flow models. However, since the most suitable areas for wind farms are in the coastal region of Lithuania, coastal orography and wind flow properties may complicate the wind modeling because of the following conditions:

- Differential heating of land and sea surfaces superimpose secondary flows (sea and land breezes) on the synoptic pattern.
- Coastal orography and large roughness changes influence the flow at sea both for off- and onshore wind.

- In areas with very cold water, such as Baltic Sea, the phenomenon known as low-level jets may bias the local climate towards higher wind speeds than those derived from the usual geostrophic approximations [21].

These mesoscale phenomena are of crucial importance for the wind field at lower levels and could be very important for wind power forecasts in the coastal region [22].

6. Conclusions

The investigations of wind resource distribution have shown that the average annual wind speed in the coastal region of Lithuania is 6.4 m/s at 50 m a.g.l. Such wind speed is similar to other countries of European Union. For this reason, the coastal region is suitable territory for wind energy development in Lithuania. There can be more suitable sites for smaller-scale wind power plant construction in the continental part and offshore but that requires more detailed investigations. Consequently the main focus on wind energy development is in coastal region, where six zones have been determined for wind power plant construction.

Electricity generation is mainly based on fossil and nuclear fuel in Lithuania. The amount of electricity produced from renewable energy sources makes only 3.7% of total electricity consumption. However, the membership in the European Union and decommissioning of Ignalina NPP presents the opportunity for the extended usage of renewable energy sources. Lithuania has assumed a commitment to reach 7% production of electricity from renewable energy sources till 2010. In order to fulfill the obligations and ensure wind power generation share additional 200 MW of wind power plants will be installed. With the increase of wind energy penetration difficulties in operating the power system related to the need of spinning reserve may occur. However, they can be solved by means of wind power prediction, which also would be a considerable promotion of the wind energy development in Lithuania.

Review of the wind power prediction models has shown that selection of most suitable prediction models for Lithuanian conditions requires detailed research and combined effort of power distributors, wind energy suppliers, Lithuanian Hydrometeorological Service and research institutions as well as support through governmental funds to encourage the research of an effective environment for future developments in the wind energy.

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